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ION CLEARING AT TERAS

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ABSTRACT

Ion trapping effect has been observed at TERAS in the measurement of betatron oscillation frequency. A combination of DC and RF clearing systems is utilized to decrease ions trapped in the electron beam. The cure for the tune shift induced by the ion trapping and the improvement of beam life are carried out with the both clearing systems.

INTRODUCTION

TERAS is the ETL electron storage ring used for synchrotron radiation research. A combination of imposition of DC clearing field on electron beam transversely and RF beam shaking is utilized for curing the ion trapping effect. In the electron storage rings, a circulating beam and synchrotron radiation (SR) ionize the residual gas molecules in the vacuum chamber. The ions induced by them are trapped in a potential well induced by stored beam and often cause detrimental effects to stored beam. The troublesome problems due to the ion trapping have been reported[1 2 3]. One of the most serious one is a tune shift observed at TERAS in the measurement of betatron oscillation frequency[4]. The tune shift can be qualitatively explained by the two beam interaction model,which describes additional focusing force being induced by trapped ions[5 6]. There are several methods of the cure for the ion trapping effect. The ion problem is solved by using a positron beam instead of an electron beam, so that ions are automatically sweep[1]. This kind of cure is expensive unless the positive generator as the injector already exists. The second method consists of putting the ion clearing electrodes inside the vacuum chamber. Such electrodes can not be simply located at a few places but must be placed all over the ring circumference[7]. As a third method,it is reported that the ion trapping effect can be alleviated with the partial filling operation,in which some of the successive RF buckets remain nearly empty[3]. The present experiment shows that the ion trapping effect can be successfully reduced by the method using the DC and RF clearing electrodes.

The expression for the tune shift with standard formula due to the ion trapping effect can be given by

$$\Delta\nu=\frac{1}{4\pi}\int\beta(s)k(s)ds \qquad k_{x,y}=\frac{e}{\gamma m_e c^2}\,\frac{\partial E_i}{\partial x,y} \tag{1}$$

where $\beta(s)$ is betatron amplitude, E_i electric field due to the trapped ions, m_e the electron rest mass γ Lorentz factor. By assuming the Gaussian distribution of the ions having σ_x and σ_y the standard deviations of electron beam, the following relation is obtained

$$\frac{\partial E_i}{\partial x,y}=\frac{d_i}{\epsilon_0}\,\frac{e}{1+(\sigma_{x,y}/\sigma_{y,x})} \tag{2}$$

where d_i is the number density of ions (m^{-3}), ε_0 the permittivity of free space. Introducing the classical electron radios r_e, the tune shift due to ion trapping effect is given by

$$\Delta\nu_{x,y}=\frac{r_e}{\gamma}\int\frac{d_e}{1+(\sigma_{x,y}/\sigma_{y,x})}\beta(s)ds \tag{3}$$

The density of ions trapped in the stored beam can be interpreted as an effective gas pressure for the intra-beam scattering process.

EXPERIMENTAL SET UP

The experimental set up is shown in Fig. 1A. The experimental system consists of the RF-KO system to excite electron beam, the observation system to detect beam oscillations and the ion clearing system. The RF-KO electrode is made from four plates parallel to electron beam and driven with RF power to make a electric field transverse to the stored beam. The horizontal and vertical distance of the parallel plates are 10 cm and 5 cm ,respectively, with the longitudinal length of 10 cm. A spectrum analyzer and its tracking generator are utilized to determine the betatron ocsillation frequency because they have high sensitivity and high fidelity as a signal source. RF source from the tracking generator is amplified with a wideband power amplifier and fed to the parallel plates. The whole frequency response of the wideband amplifier and the RF-KO electrode varies monotonically within 5 % over the frequency range concerned. The power level of RF supplied to the RF-KO electrode is suitably adjusted for the excitation not to give an excessive driving power. It is also known that the excitation has to be modulated in order not to pull the betatron frequency alone with the tracking. The amplitude modulation is made with a square wave with a frequency of 1 kHz and a width of 120 μsec. To detect the resonance oscillation of the electron beam, the visible part of SR from the beam is focused on a pin hole with an optical lens and led to a photomultiplier on which the beam image is made. Geometrical arrangement of the detection system is shown in Fig. 1B. Coherent response of the beam to the excitation is measured by analyzing the output signal from the photomultiplier. The DC clearing system consists of argon glow discharge electrodes which are set inside the vacuum chambers of bending magnets at a distance of about 5 cm from the electron beam trajectory. The electrostatic field is also supplied onto a pair of parallel plates of the RF clearing system. RF power is also fed to this parallel plates together with a DC

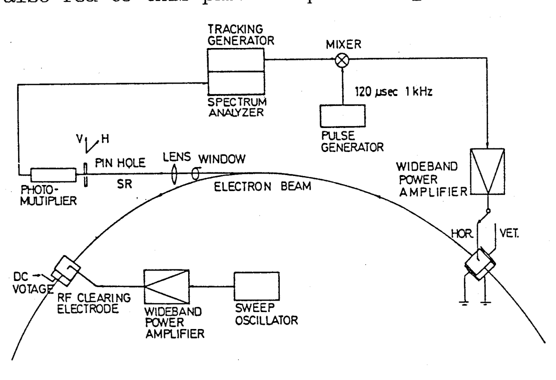


Fig. 1A Experimental set up for the Rf-KO method and the ion clearing systems

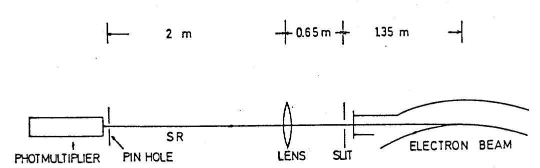


Fig. 1B Geometrical arrangement of the measurement of betatron oscillation

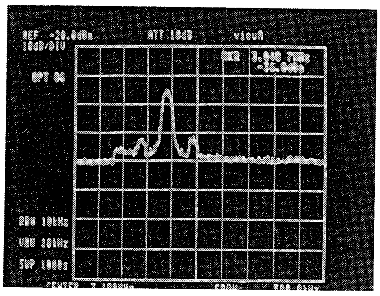


Fig. 2 Frequency spectrum of the coherent resonance at 606 MeV, span 500 kHz

field in order to shake the electron beam and cancel the attractive potential trapping the ions. The typical spectra obtained are shown in Fig. 2 at 607 MeV for low current. Synchrotron sideband produced by the frequency modulation due to the machine chromaticity can be clearly seen: their distance is the synchrotron frequency and their width is the natural tune spread in the beam, mostly due to ripple in the quadrupoles. This picture was taken under the rather good condition,i.e. the stored current is low and therefor ion trapping effect is little. The tune, ν,is related to be the excitation frequency, f, by

$$\nu - \mathrm{INT}(\nu) = f/f_0 \qquad f_0 = 9.5366\ \mathrm{MHz} \qquad (4)$$

where f_0 is the revolution frequency.

The RF power driving the clearing system is 150 W, the corresponding potential difference between each electrode is 214 V at the driving frequency of around 1 MHz.

DISCUSSION OF EXPERIMENTAL RESULTS

In the frequency distributions of the resonance oscillations, the peaks and widths of individual lines can be found to be depend on the electron currents. Spectra for very low current electron beams do not exhibit tune shift and large tune spread. Shifts of the peak positions are the phenomenon characterized by the existence of threshold currents as does any instability. Fig. 3 shows a typical tune shift as a function of electron beam current at 606 MeV. The ratio of the tune shift to the store current depends on electron energy ($\delta\nu_H$/stored current = 0.65 A^{-1} at 606 MeV, 0.21 A^{-1} at 713 MeV). The slopes of the straight line exhibits the positive tune shift and suggests that positive ions trapped in the path of the electron beam act as focusing force onto electrons. The tune shift can be evaluated from the difference between the low and high current spectra. Measured values of ion density are given in Fig. 4.

Fig. 5 shows the result of measurement the betatron oscillation frequencies for various DC clearing field. The tune shift at low current can be

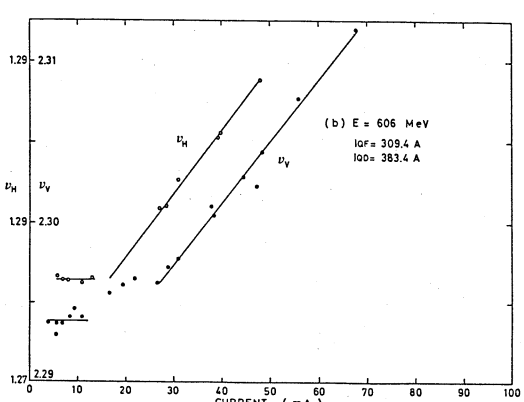


Fig. 3 The tune shifts with the stored current at 606 MeV

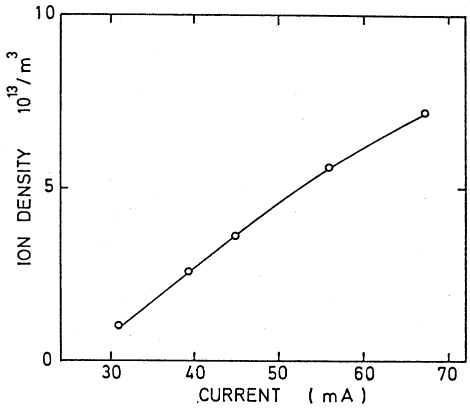


Fig. 4 The density of ions trapped with the stored current at 606 MeV

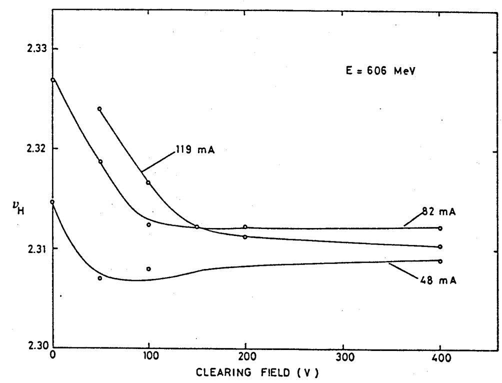


Fig. 5 The tune shifts vs the DC voltage onto the ion clearing system

reduced by applying low voltage to DC clearing electrodes. The effect of the DC clearing on the tune shifts saturates above 400 V even for the stored current less than 120 mA. Moreover, the tune shifts due to ion trapping increases, on the contrary, supplying the DC voltage more than 400 V. Photoelectrons from the DC electrodes are accelerated by the clearing field and hit the surface of the vacuum chamber. This

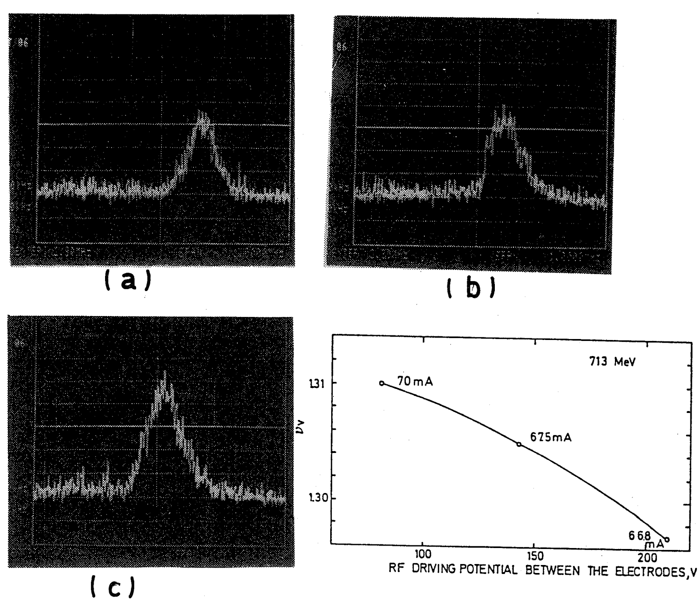


Fig. 6 The tune shift with various RF driving potential, (a) 80 V, (b) 140 V and (c) 214 V. The center frequency 2.7 MHz, spane 1 MHz

results in the desorption of molecules on the surface. These desorbed molecules also affect the electron beam. The electrostatic voltage of about 400 V is applied to the DC clearing system during the electron injection and storage.

The trapping effect is supposed to affect strongly low energy electrons. During the injection of 320 MeV electrons, tune shift will be so large and operating points get close to the third resonance line (ν_h = 7/3). The suppression of the trapping effect improves the beam accumulation effectively and increases the maximum stored current to 260 mA at the injection of 320 MeV electrons. The independent use of a DC clearing field can not perfectly clear the ions. The RF power is supplied to the RF clearing system being accompanied with the DC clearing field. The decreasing of tune shifts by the RF ion clearing depends on RF power as shown in Fig. 6. During the experiment of RF ion clearing, TERAS is not in so good condition just after installation of new RF cavity for 18 bunches operation. Trapped Ions effect seriously on electron beam and therefore the RK-KO method can not effectively excite the resonance oscillation of the electron beam. Amplitudes and shapes of the resonance oscillations vary with the RF power supplied. It is found that the peak height of resonance ocsillation increases with the increase of the RF power and betatron ocsillation frequencies can be more easily determined by getting ion density lower.

The transverse distribution of the density of ions can be assumed to duplicate approximately with the distribution of electrons. The stored beam feels the potential induced by trapped ions and the potential varies according with the density of ions. The tune shifts due to ion trapping effect are supposed to vary with the position of electrons inside the beam size. Fig. 7 shows the expected differences in tune shifts measured by scanning a pin hole along the vertical coordinate. This differences correspond to ion densities and the shapes of potential wells trapping ions can be estimated in Fig. 8.

As the stored beam increases, a vertical beam blow-up is observed on a TV display. When RF clearing fields are turned on, the vertical blow-up of the beam is reduced as shown in Fig. 9 and beam lifetime becomes longer as shown in Fig. 10. Fig.10 gives the decay rate plot as a function of the stored current. The small beam size and the long lifetime are often contradictory phenomena. In the present stage, the elastic scattering of the stored beam with residual gas molecules can be explained to determines the lifetime of TERAS. The improvement of decay rate trends to decrease as the beam current is getting low. The improvement of the lifetime against the ion trapping effect can not be observed in the decay rate around 20 mA as shown in Fig. 10 is shown. 4The ion trapping effect can not be suppressed even by the combination of the DC and RF clearing systems.

REFERENCES

1) M.E.Biagini et al, Observation of Ion Trapping at ADON , Proc. 11th Int. Conf. on High Energy Accelerators, CERN, (1980) 687
2) T.Kasuga et al, Ion-Trapping Effect in UVSOR Storage Ring, Jpn. J. Appl. Phys. 24 (1985) 1212.
3) S.Sakanaka et al, Differences in the Ion Trapping between Uniform and Partial Bunch Filling, KEK Preprint 86-61 (1986)
4) S.Sugiyama et al, Measurement of the Betatron Oscillation Frequency in TERAS by RF Knock out Method, TELL-TERAS Activity Report (1980-1986) 30
5) R.G.Gluckstern and A.G.Ruggiero, Ion Production and Trapping in Electron Ring, BNL-26585
6) R.D.Kohaupt, Mechanismus der Ionenabsaugung im Elekton-Positron-Speicherring, Intrnen Bericht DESY HI-71/2 Dezember 1971
7) T.Kasuga, Ion-Clearing System of UVSOR Storage Ring, Jpn. J. Appl. Phys. 25(1986)1711

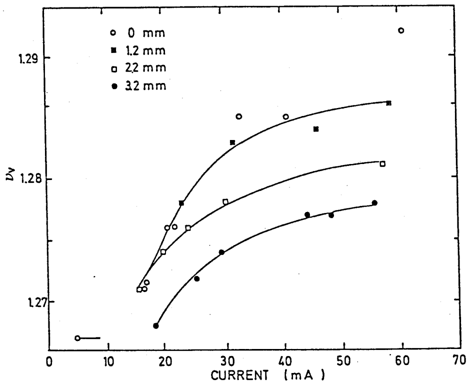


Fig. 7 The tune shift for the stored current at different position of vertical coordinate in the electron beam size at 713 MeV

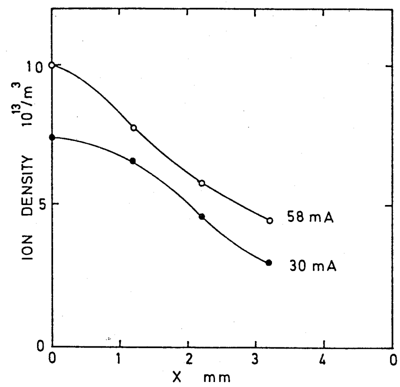
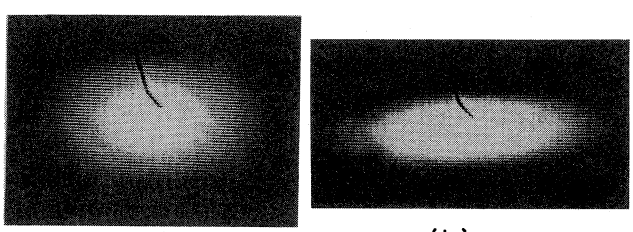


Fig. 8 The distribution of the density of ions at 713 MeV



(a) (b)

Fig. 9 The change of beam profile for 92 mA (a) with RF excitation off, (b) with RF excitation on

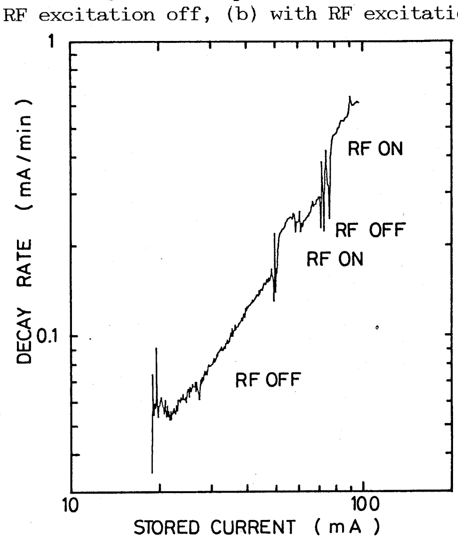


Fig. 10 Improvement of the decay rate with RF excitation